Journal of Structural Engineering & Applied Mechanics (2023) 6(3):249-256
DOI 10.31462/jseam.2023.03249256

RESEARCH ARTICLE

Examination of acoustic properties of polymer-coated nonwoven textile samples

Gözdenur Ulu, İkilem Göcek*

Istanbul Technical University, Faculty of Textile Technologies and Design, Istanbul, Türkiye

Article History

Received 09 May 2023
Accepted 04 August 2023

Keywords

Acoustic performance
Sound absorption
Sound transmission loss
Polymer-coated nonwovens
Acoustic textile
Automotive textile
Impedance tube method

Abstract

In this study, different types of polymeric layers were coated in different weights (g/m^2) on nonwoven fabrics by extrusion process and then, sound absorption and transmission loss properties of each sample were examined. Nonwoven fabrics were produced from polyester (PET) fiber, formed by the carding process and bonded by the needle punching process. These samples were tested between 50-6000 Hz frequency range to reveal the effect of polymer layer type and weight coated on nonwoven fabrics on the sound absorption and transmission loss performance at the low, medium, and high-frequency values. Polymer layers were coated with the weight of 400 gsm and 800 gsm. Nonwoven fabric samples coated with polyethylene or polypropylene layers and nonwoven fabric samples without polymeric coating were tested by using an impedance tube and compared in terms of sound absorption and transmission loss performance. In the test system, two sides of the samples were tested separately. It was seen that the sound absorption performance of the samples changed in case the sound wave was first incident to the polymeric layer or nonwoven layer.

1. Introduction

Unwanted sound that disrupts the normal activity of both humans and animals is referred to as noise pollution. Despite the advancements brought about by the industrial revolution, noise pollution continues to be a persistent problem worldwide. While it was once considered to be harmless, it is now recognized as a significant threat to people's health due to its potential to cause mental illnesses, distract attention, and lead to physical illnesses. To counteract the negative effects of noise pollution and reduce the levels of reverberant noise, acoustic insulation materials are frequently used [1]. In recent years, the use of textile materials in acoustic applications has been quite remarkable. Nonwoven fabrics are preferred for these applications because of their high porosity and low-cost features. Due to their several advantages over woven or knitted fabrics, the automotive industry is progressively adopting non-woven fabrics. Non-woven fabrics are widely used worldwide in various applications including carpets, floor coverings, headliners, boot linings, parcel shelves, door panels, roof linings, dashboard panels, battery separators, car seats, acoustic insulation, and many others [2]. Effective control of interior noise in modern vehicles is crucial for manufacturers, as it is now a key competitive quality characteristic. Traditional noise and vibration control methods typically focus on managing different noise sources, transmission paths, and receivers. In the automotive industry,

* Corresponding author (goceki@itu.edu.tr)
eISSN 2630-5763

controlling noise sources, as well as airborne and structure-borne paths, are the primary approaches. Manufacturers commonly achieve noise control in vehicles by incorporating materials that provide mechanical damping, sound absorption, or sound insulation, or sometimes by incorporating some materials possessing one or more of these properties. Barrier materials are also employed to enclose noise sources, and their noise insulation performance is determined by their mass, as characterized by the sound transmission loss (TL) measured in dB [3].

One of the most notable technical applications of nonwoven materials is their use as acoustic absorbents. Acoustics is the branch of science that deals with the study of sound and its various effects, including reflection, refraction, absorption, diffraction, and interference. Sound can be considered a physical phenomenon, where sound waves are longitudinal and cause particles to temporarily displace in a parallel direction to the energy transport before returning to their original position [4].

The acoustic properties of materials can be divided into three categories: propagation, absorption, and scattering, which can be measured by airflow resistance, acoustic transmission loss, acoustic absorption coefficient, and acoustic scattering coefficient. Sound waves interact with surfaces and can be absorbed, transmitted, reflected, refracted, or diffracted, depending on the type of surface [5]. Sound-absorbing materials are utilized in various areas of noise control engineering to decrease sound pressure levels. To use them effectively, important physical attributes and parameters that cause a material to absorb sound should be identified. Synthetic fibrous materials made from minerals and polymers are mostly used for sound absorption and thermal isolation. Polyurethane and melamine foams are the most commonly used cellular porous sound-absorbing materials. Perforated panel absorbers have been used for many years in noise control and are effectively made up of a large number of individual Helmholtz resonators that dissipate acoustical energy into heat [6]. The sound absorption coefficient (SAC) is used to determine how well materials absorb sound, with values ranging between 0 and 1. Low-frequency sound waves are more difficult to absorb than high-frequency waves. Two methods, the reverberation chamber and impedance tube methods, are used to measure sound absorption. The reverberation chamber method is used for larger samples, while the impedance tube method is preferred for smaller sample sizes. The sound absorption coefficient can be calculated for both low and high-frequency ranges, and average values are reported [7].

While the sound absorption performance of nonwoven fabrics is high in medium and high frequencies (>1000 Hz), it is pretty low in low frequencies [8-10]. Therefore, it is required to enhance the acoustic properties of nonwoven fabrics for sound absorption in low frequencies.

According to marketing research for automotive and construction sectors, the weight of currently used fiber-based nonwoven fabrics is more than 2000 gsm. Also, materials used as heavy layers have a minimum 3000 gsm weight. In this study, for these two sectors, polymer-coated nonwoven fabric samples, that are formed by coating of polymer layers via the extrusion process on the PET-based nonwoven fabric, were tested and their acoustic performance was evaluated. Sound absorption coefficient and transmission loss values of nonwoven fabric samples with polymeric coating in different types and weights were determined by using an impedance tube.

Table 1. The details of the test samples

Sample code	Detail
A	PET-based nonwoven fabric
B	PET-based nonwoven fabric with 400 gsm PE coating
C	PET-based nonwoven fabric with 800 gsm PE coating
D	PET-based nonwoven fabric with 400 gsm PP coating
E	PET-based nonwoven fabric with 800 gsm PP coating

2. Experimental study

In the experimental study, sound absorption coefficient and transmission loss values for a total of five samples were determined by using an impedance tube. The details of the test samples by which the type of polymer coating and the weight of polymer coating have been investigated are as follows;

2.1. Sound absorption coefficient

Sound absorption tests were performed by using an impedance tube according to the ISO 10534-2 test standard. Experiments in large and small tubes were done and the data obtained were merged by the test software.

2.2. Transmission loss

Transmission loss tests were performed by using an impedance tube according to the ASTM E2611-09 test standard. Experiments in large and small tubes were done and the data obtained were merged by the test software.

3. Results

3.1. Sound absorption properties

The sound absorption behavior of the samples was investigated in the frequency range of 50-6400 Hz. Fig. 1 illustrates the sound absorption coefficient variation of the test samples A, B, C, D, and E. As seen in Fig. 1, sample A has higher sound absorption coefficient (SAC) values in the higher frequencies.

3.1.1. Polyethylene-coated samples (sample B and sample C)

According to Fig. 2, the SAC data of B-P is almost the same as that of sample A until 785 Hz. B-P has higher SAC values than that of the A in nearly 785-1605 Hz frequency range. From 1605 Hz to 2365 Hz approximately, the SAC values belonging to B-P are lower than that of the A. In the 2365-2988 Hz frequency range B-P has higher SAC values than that of the A and in the 2988-6400 frequency range has lower SAC values than that of the A again. When the B-P reaches to 0.20 SAC value at 1021 Hz, sample A has a 0.06 SAC value. Moreover, the SAC value of B-P is 0.22, and of A is 0.07 in 1435 Hz frequency. The highest SAC value of B-P is 0.27 at 2702 Hz, while A has 0.14 SAC values at the same frequency.

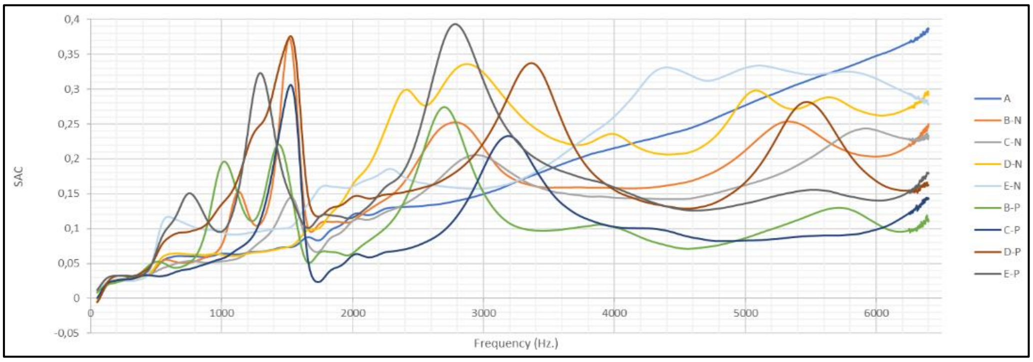

Fig. 1. Sound absorption coefficient variation of the test samples in the case sound wave was first incident to the polymeric layer (B-P, C-P, D-P, E-P) or the nonwoven layer (B-N, C-N, D-N, E-N)

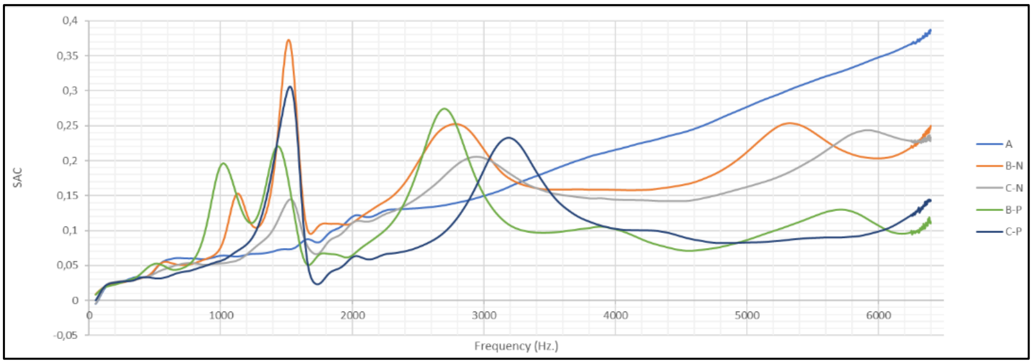

Fig. 2. Sound absorption coefficient variation of the test samples A, B, and C in the case sound wave was first incident to the polymeric layer (B-P, C-P) or the nonwoven layer (B-N, C-N)

SAC data of the B-N is almost the same as that of the sample A until 943 Hz. The B-N has higher SAC values than that of the A in nearly 943-1674 Hz frequency range. In Fig. 2, there are peaks belonging to the B-N at 1131 Hz and 1517 Hz. At 1131 Hz, the SAC value of the B-N is 0.15 while the SAC value of the A is 0.06. Also, B-N has a 0,37 SAC value at 1517 Hz while A has 0.07 at the same frequency. In the 1696-2094 (approximately) Hz frequency range, SAC data of the B-N approximates that of the A. There is a peak for B-N in the range 2094-3259 Hz (exactly at 2785 Hz) where B-N has the highest SAC value of 0.25 whereas A has a 0.14 SAC value at 2785 Hz. However, B-N has lower SAC values than A above 3259 Hz.

In Fig. 2, the C-P curve continues almost same as the curve A until 1078 Hz, after that, it captures an increasing trend. In the 1078-1656 Hz frequency range there is a peak for the C-P curve at 1528 Hz where the SAC value is 0.31. At the same frequency (1528 Hz) SAC value of A is 0.07. The data of C-P is lower than that of the A in the frequency range of approximately 1656-2907 Hz. There is a small peak for the C-P at 3190 Hz where the SAC value is 0.23. The SAC value of the A is 0.16 at the same frequency (3190 Hz). The C-P curve proceeds below the curve A from 3420 Hz to 6400 Hz.

The curve C-N is almost the same as curve A until approximately 1208 Hz, after that, there is an increasing trend until approximately 1536 Hz. Then, it begins to decrease. In the 1645-2383 Hz frequency range, curve C-N is almost the same as curve A again. There is a peak at 1536 Hz for the C-N where SAC is 0,14 whereas the SAC value of A is 0.07. There is an increasing trend for C-N from 2383 Hz to approximately 2933 Hz. At 2933 Hz, the SAC value of the C-N is 0.21 while that of the A is 0.15. Above 2933 Hz, the SAC value of the C-N decreases and from 3294 Hz to 6400 Hz the C-N curve becomes below the curve A.

3.1.2. Polypropylene-coated samples (Sample D and Sample E)

In Fig. 3, the sample D-P has higher SAC values than that of the A in the 355-3758 Hz frequency range. The D-P curve has three peaks. In the range of approximately 355-1537 Hz, there is an increase just after that there is a rapid decrease until 1728 Hz for the D-P curve. It follows a stable trend in the range of 1728-2641 Hz which is similar to that of curve A although all of the values for the D-P are higher than that of the A. Then, the SAC values of the sample D-P increase again until 3367 Hz and begins to decrease. From 3745 Hz on, the curve D-P becomes below the curve A. Here, it is observed that the SAC value is 0.37 for the D-P whereas that of sample A is 0.07 SAC at 1537 Hz. The second peak is at the 3367 Hz where the SAC value is 0.33 for the D-P and 0.18 for the A. Above 3745 Hz, the SAC values for the D-P curve are lower than that of the sample A however, although the D-P curve approaches the curve A at around 5479 Hz frequency, then again gets further away from the curve A.

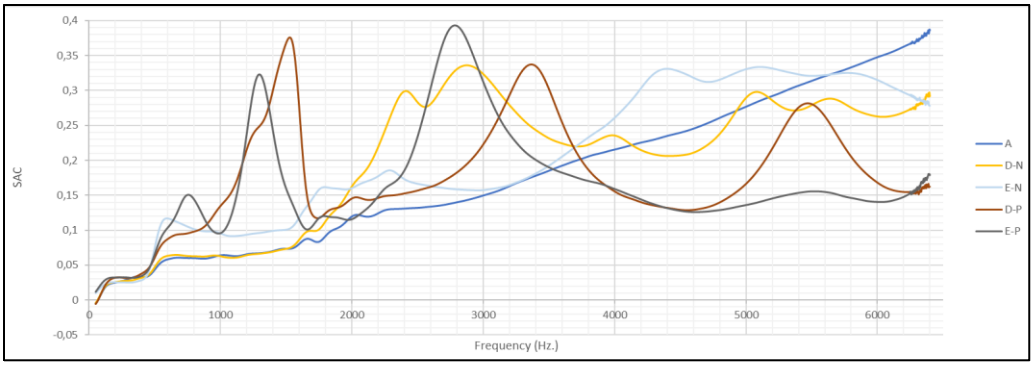

Fig. 3. Sound absorption coefficient variation of the test samples A, D, and E in the case sound wave was first incident to the polymeric layer (D-P, E-P) or the nonwoven layer (D-N, E-N)

The D-N curve is almost the same as the curve A until 1500 Hz and then it captures an increasing trend until 2424 Hz. At the 2424 Hz frequency, a 0.3 SAC value is reached by sample D-N where the SAC value of sample A is 0.13. Just after there is a slight decline, then again there is a slight increase. It is seen that the SAC value reaches 0.34 at 2882 Hz. However, at the same frequency (2882 Hz), sample A has a 0.14 SAC value. From 2882 Hz to 3745 Hz, there is a decreasing trend for the D-N curve. Above 3745 Hz, the D-N curve is mostly just below curve A and shows a more wavy structure than curve A.

The curve E-P has better SAC values than the curve A until 3540 Hz and then it remains under the curve A. The curve E-P has three prominent peaks until 3540 Hz whereas there is none after 3540 Hz. According to Fig. 3, the sample E-P reaches a maximum of 0.39 SAC at 2800 Hz. Sample E-N has generally higher SAC values than sample A with a maximum of 0.33 SAC at 4365 Hz. The curve E-N does not have prominent peaks.

3.2. Transmission Loss Properties

Sound transmission loss properties of the samples were investigated in the frequency range of 50-6400 Hz. Fig. 4 illustrates the transmission loss (TL) variation of the test samples A, B, C, D, and E.

As seen in Fig. 4, while sample A has higher transmission loss values at low frequencies (approximately 50-1745 Hz.), there is a sudden decline at 1745 Hz and it continues to have low transmission loss values constantly up to 6400 Hz. Also, it is observed that mostly, there is not much change in the transmission loss values in the case the sound wave is firstly incident to the polymeric layer or the nonwoven layer.

3.2.1. Polyethylene-coated samples (Sample B and Sample C)

According to Fig. 5, the sample B (B-N and B-P) has transmission loss values generally between 5-42 db. Below 1745 Hz, sample B (B-N and B-P) has lower transmission loss than that of sample A. In that range, sample B (B-N and B-P) has a maximum 30 dB transmission loss value while sample A has nearly as much as 80 dB. At 1745 Hz, the sample B (B-N and B-P) doesn't have a sudden decline like the sample A. Above 1745 Hz, the sample B (B-N and B-P) continues with slight peaks. It is seen in 4443 Hz that sample B has 42 dB transmission loss, while sample A has 2.7 dB transmission loss.

Sample C (C-N and C-P) has similar variations in the transmission loss to that of sample A until 1745 Hz frequency. There is a sudden decline to 10 dB and 13 dB transmission loss for C-P and C-N, respectively at 1745 Hz after which the curve continues with a similar trend to that of sample B. Above 1745 Hz, sample C has greater transmission loss values than that of the sample A. The curve of the sample C is more wavier than that of the sample B.

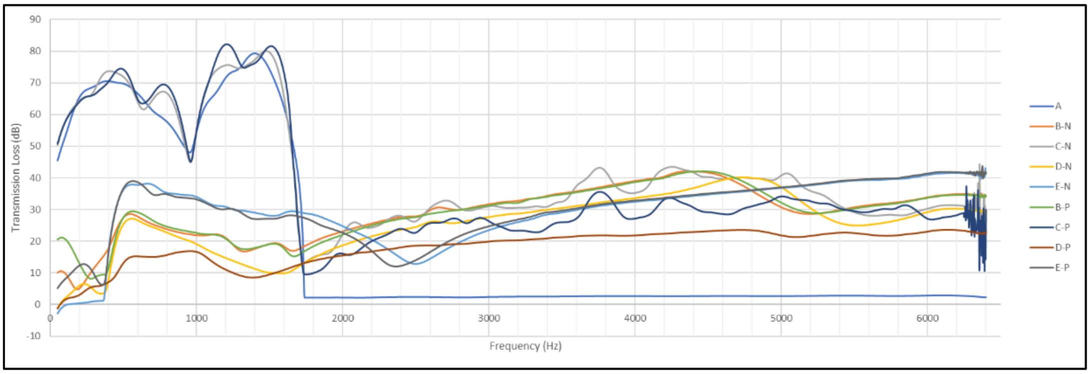

Fig. 4. Transmission loss variation of the test samples in the case sound wave was the first incident to the polymeric layer (B-P, C-P, D-P, E-P) or the nonwoven layer (B-N, C-N, D-N, E-N)

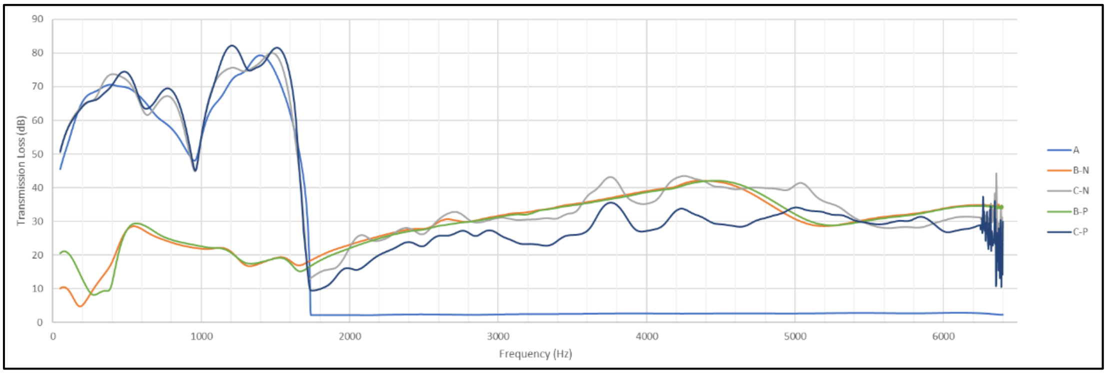

Fig. 5. Transmission loss variation of the test samples A, B, and C in the case sound wave was firstly incident to the polymeric layer (B-P and C-P) or the nonwoven layer (B-N and C-N)

3.2.2. Polyethylene Coated Samples (Sample B and Sample C)

As seen in Fig. 6, D-N mostly has a higher transmission loss than that of D-P over the entire frequency range. Below 1745 Hz, the D-N has transmission loss values between nearly 0-28 Hz. The transmission loss of the sample D-N declines to approximately 12 dB at 1745 Hz and then it rises slightly until it reaches nearly 40 dB at 4770 Hz. On the other hand, while sample D (D-N and D-P) has a lower transmission loss than that of sample A below 1745 Hz, it has a higher transmission loss than that of sample A over 1745 Hz.

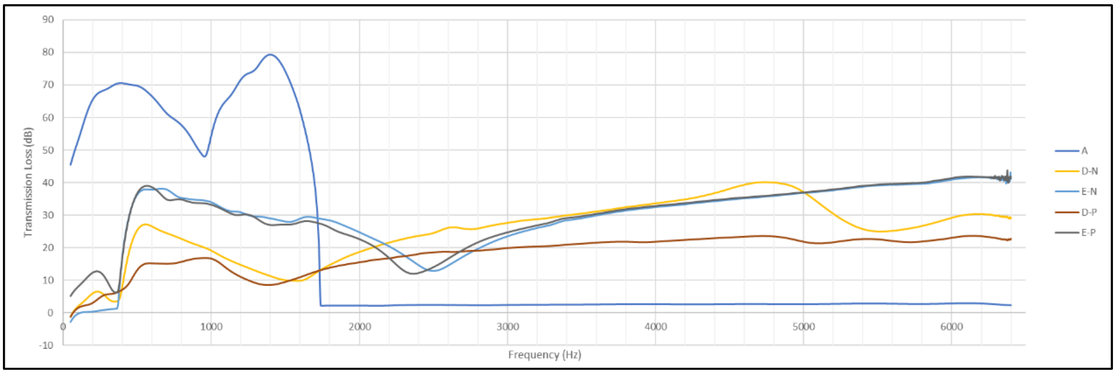

Fig. 6. Transmission loss variation of the test samples A, D, and E in the case sound wave was first incident to the polymeric layer (D-P and E-P) or the nonwoven layer (D-N and E-N).

Sample E (E-N and E-P) has lower transmission loss values than that of sample A however mostly higher than sample D (D-N and D-P) below 1745 Hz. Above 1745 Hz, the curve E (E-N and E-P) firstly declines until 2500 Hz and then it increases slightly until 6400 Hz. At nearly 5500 Hz, sample E (E-N and E-P) has a 40 dB transmission loss while sample A has a 2.7 dB transmission loss. In this region from 1745 to 6400 Hz, sample E has higher transmission loss than that of sample A.

4. Conclusion

Nonwovens are known to be good sound absorbents at high frequencies. Hence, development is required for nonwovens to be used as sound absorbents at low frequencies, too. However, there is a limited number of studies in the scientific literature regarding the examination of nonwoven samples' acoustic properties in terms of different parameters. Therefore, in this study, two polymers, i.e., polyethylene and polypropylene are coated on the PET-based nonwoven in two different weights 400 gsm and 800 gsm. Test results show that polymer coating on a nonwoven sample affects the acoustic performance i.e. sound absorbency and sound transmission loss. Moreover, polymer type, polymer weight, and the arrangement of the layers are some important factors that affect the acoustic properties. It has been observed that polymer coating on nonwoven samples may provide better sound absorbency properties, especially at lower and medium frequencies, however, the behavior is changeable and affected by frequency. If the sound absorbency property is evaluated in terms of polymer type, it can be said that polypropylene coating is superior to its polyethylene counterpart. Moreover, the weight of the polymeric layer affects the sound absorbency coefficient. The effect is different according to frequency, polymer type, and the surface where the sound wave is firstly incident to. The curves belonging to the 400 gsm polyethylene coated sample (B-N and B-P) are similar in general terms. It is seen that B-N has better SAC values than that of B-P. There is no significant difference between C-N and C-P and the distribution of their data is similar. However, C-P has the greatest peak at 1578 Hz where SAC is 0.31. Sample A reaches the same SAC value above 5000 Hz. In the 1888-3187 Hz range, the best SAC results belong to the D-N curve. Above 3743 Hz, the curves D-P and D-N are below the curve A. However, the curve D-N is closer to the curve A than the curve D-P. Results of sample E shows that sample E-P has good sound absorption property in narrow frequency ranges. In this study, it has also been observed that the nonwoven sample does not have good transmission loss at high frequencies. However, polymeric coating significantly enhances the sound transmission loss of the nonwoven at high frequencies. Increasing the polymeric coating weight has different effects in different frequency ranges. It is seen that there is no significant difference in the distribution of transmission loss data for polyethylene and polypropylene over the entire frequency range. Moreover, it can be said that the arrangement of the layers just affects the sound absorbency coefficient. Because the sound absorbency coefficient is the ratio of the absorbed energy to the incident energy. Since energy is absorbed by the layer the sound wave is incident to, the arrangement of the layers has changed the sound absorbency coefficient as it is expected.

Acknowledgments

The authors would like to express their gratitude to Hassan Tekstil Sanayi ve Ticaret Anonim Şirketi for opening up their facilities for the production of the samples of the current study and in particular to Mr. Burak Dalbudak for his support.

Conflict of interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This research received no external funding.

Data availability statement

No new data were created or analyzed in this study.

References

[1] Viju S (2021) Acoustic insulation by textile fibres. International Journal of Mechanical Engineering 6(3):221-223.
[2] Joshi M, Adak P (2018) Rubber Nanocomposites and Nanotextiles in Automobiles, Chapter 6. Walter de Gruyter GmbH. https://doi.org/10.1515/9783110643879-006
[3] Arenas JP, Li Z (2021) Biocomposite and Synthetic Composites for Automotive Applications, Chapter 12. Woodhead Publishing Series in Composites Science and Engineering. https://doi.org/10.1016/B978-0-12-820559-4.00012-2
[4] Rosa EV, Olivera FR, Santos IFD, Steffens F (2021) Potential use of nonwoven for acoustic absorption. Brazilian Journal of Development 7(2):20582-20598. https://doi.org/10.34117/bjdv7n2-618
[5] Paul P, Mishra R, Behera BK (2021) Acoustic behaviour of textile structures. Textile Progress, 53(1):1-64. https://doi.org/10.1080/00405167.2021.1986325
[6] Çelikel DC, Babaarslan O (2018) Acoustic insulation behavior of composite nonwoven. Engineered Fabrics p. 41-58.
[7] Hassan T, Jamshaid H, Mishra R, Khan, MQ, Petru M, Tichy M, Muller M (2021) Factors affecting acoustic properties of natural-fiber-based materials and composites: A review. Textiles 1(1):55–85. https://doi.org/10.3390/textiles1010005
[8] Barron R (2003) Industrial Noise Control and Acoustics. Marcel Dekker, Inc, New York.
[9] Peters R, Smith B, Hollins M (2013) Acoustics and Noise Control, Third Edition. Routledge, New York.
[10] Nayak R, Padhye R (2016) Acoustic textiles: an introduction. Textile Science and Clothing Technology p. 1-32.